Verification of the BLAST Computer Program for Houses

A RESEARCH REPORT

Establishing the BLAST Program as a Basis
for the Evaluation of Various Simplified
Energy Analysis Computer Programs.

A Project of the
Energy Conservation and Oil Substitution Branch
Energy, Mines and Resources Canada

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The Buildings Energy Technology Transfer Program (BETT) of EMR has been created to assist building owners, users and practitioners active in the design, construction and operation of buildings in identifying technical obstacles to energy conservation. Through a nationwide network of research agencies and private sector consultants, BETT carries out research and development projects and provides the audiences mentioned above with technical reports, how-to manuals, training manuals, audio-visual aids and data bases to help them overcome these obstacles.

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ABSTRACT/RESUME

EMR has initiated a study to compare the relative merits of several simplified energy analysis computer programs within the context of low-rise residential buildings. As a first step, a detailed computer simulation program (BLAST) was selected as the base-line for comparsion, and verified against results monitored at the University of Alberta Thermal Test Facility. It was concluded that BLAST would provide an accurate prediction of the monthly power consumptions of a set of standard house models, for verification of the simplified programs.

* * *

Energie, Mines et Ressources Canada a entrepris de comparer plusieurs programmes simplifiés d'analyse du rendement énergétique en ce qui concerne les immeubles résidentiels de quelques étages. Dans un premier temps, on a choisi, comme point de comparaison, le programme BLAST qui permet une simulation informatique détaillée, dont on a vérifié l'exactitude, en en comparant les prévisions aux données relevées au centre d'essai thermique de l'Université de l'Alberta. Il ressort de la vérification exécutée que le programme BLAST permettrait de prédire avec exactitude la consommation mensuelle d'énergie d'un ensemble de maisons ordinaires aux fins de la vérification de programmes simplifiés.

Le lecteur trouvera un sommaire en français de ce rapport à la page i.

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On a établi ces dernières années divers programmes informatiques et méthodes de vérification visant à prévoir le rendement thermique des maisons. Bien que beaucoup de ces programmes sont maintenant très répandus, il n'y a pas encore eu d'efforts concertés pour essayer de vérifier l'exactitude de chacun. Aussi, en vue d'amorcer cette évaluation, on a choisi comme point de comparaison le programme BLAST, qui donne des prévisions détaillées, d'heure en heure. (On a dû retenir un programme informatique comme point de comparaison, car il n'existe pas de données comparatives mesurées pour un ensemble de maisons "identiques" situées à plusieurs endroits au Canada.) Le présent rapport fait état du procédé employé pour vérifier l'exactitude du programme BLAST à l'aide de données relevées dans deux maisons, au centre d'essai thermique de l'Université de l'Alberta.

La vérification supposait la comparaison des prévisions du programme aux données horaires, journalières, hebdomadaires, mensuelles et annuelles de température et de consommation d'énergie effectivement relevées dans deux maisons, l'une à bon rendement énergétique et l'autre de type traditionnel.

Les prévisions du programme BLAST à l'égard des deux maisons se fondaient sur les données météorologiques relevées d'heure en heure et sur les coordonnées géométriques et fonctionnelles spécifiées par l'Université de l'Alberta.

Les données météorologiques provenaient du Service de l'environnement atmosphérique et ont été relevées à 16 kilomètres environ du site de l'essai. Elles n'étaient pas identiques à celles qui ont été relevées sur le site même, mais c'étaient les meilleures dont on disposait. De plus, comme il s'agissait des données d'un microclimat semblable à celui du site de l'essai, on a jugé que leur emploi ne fausserait pas vraiment les prévisions.

On a comparé les prévisions faites par le programme BLAST aux données horaires relevées au cours de périodes de trois jours consécutifs, à différents moments de l'année. Il a fallu procéder ainsi parce que le relevé ne se faisait pas de façon continue sur le site de l'essai. On a également fait l'évaluation des données journalières au cours de ces périodes. Enfin, on a examiné les prévisions du rendement thermique pour chaque mois.

Les prévisions du programme BLAST concordaient en général avec le rendement thermique mesuré. Les écarts observés peuvent être dus à plusieurs facteurs : d'abord, les données météorologiques fournies par le Service de l'environnement atmosphérique ont été relevées à plusieurs kilomètres du site de l'essai; ensuite, la résistance thermique effective calculée et employée pour le programme BLAST ne correspondait pas parfaitement aux données mesurées sur les murs des maisons; enfin, la corrélation d'infiltration a été extrapolée à partir de mesures s'étendant sur trois mois, et les températures du sol employées pour les prévisions se fondaient sur celles de l'endroit le plus rapproché (à 100 km de là) où l'on pouvait faire des relevés.

On aurait pu diminuer certains de ces écarts, pour faire mieux concorder les données. Toutefois, on ne pouvait pas justifier d'y consacrer le temps et les efforts que cela supposait. On a convenu que les comparaisons obtenues suffisaient pour vérifier le modèle BLAST : les prévisions annuelles de consommation d'énergie produites par ce programme étaient de 7,6 p. 100 supérieures aux données mesurées sur les lieux, dans le cas de la maison à bon rendement énergétique, et de 1,0 p. 100 supérieures aux données mesurées, dans le cas de la maison traditionnelle.

Over the last few years a number of computer programs have been developed for predicting the thermal performance of a building. Some of these programs involve hour-by-hour simulations which require detailed input of the building construction and climatic conditions. Other programs involve simplified calculations of either monthly or annual performance based on average climatic conditions and simplified building construction detail. These energy analysis computer programs are now becoming an increasingly important tool in the design of new buildings and in the diagnosis of existing building performance.

As part of its future plans, Energy, Mines and Resources, Canada is contemplating the use of one or more of these computer programs for design and evaluation in national energy conservation programs such as CHIP or COSP. This raises questions about the relative merits and accuracies of the various computer programs. Although many of the programs are now being used fairly intensively, there has never been a broad-based attempt to compare the relative merits of each program. Therefore, there are not enough comparative data to allow selection at the present time.

As a first step in selecting the most suitable programs, EMR has initiated a study through its Buildings Energy Technology Transfer Program. This study will conduct a detailed comparative investigation of eight popular simplified computer programs and analysis procedures, within the context of low-rise residential buildings. The programs, their owners and authors are listed in Table 1.1. It should be noted that all of the programs are currently in use, with the exception of the CHIP EVALUATION program. At the time of writing, the CHIP EVALUATION was thought to be not yet ready for use.

The investigation was conducted in two phases. In the first phase, the Building Loads Analysis and System Thermodynamics, Version 3.0 (BLAST) computer

TABLE 1.1
PROGRAMS TO BE EVALUATED

PROGRAM	OWNER	AUTHOR	COMMENTS
ECAP	EMR	Millbank Associates, IEA Consulting, and Argue Consulting.	Available on Osborne portable personal computer. Used as auditing tool in Prince Edward Island, Newfoundland, Northwest Territories and Yukon.
HOTCAN	NRC	Division of Building Research, Saskatoon	User-friendly program available on Northstar personal computer.
ENERSAVE	EMR	P.E.I. Department of Industry and Commerce, Applied Urbanetics Inc., and Scanada Consultants	Questionnaire completed by homeowner and mailed to EMR for solution. Gives recommendation for conservation retrofits and potential savings.
CMHC - 2	CMHC	Based on HOTCAN	Provides more detailed cost analysis on minicomputers
REAP	Ontario Hydro	Ontario Hydro	Designed for houses being converted to electric heat. Gives potential savings from retrofits.
CALMERES	Quebec Hydro	Quebec Hydro	Designed for houses being converted from oil to electric heating. Available on main frame computer.
CHIP EVALUATION	EMR	Energy Building Group	Designed to evaluate CHIP grant.
DEGREE-DAY METHOD	N/A	A.S.H.R.A.E.	Hand calculations method based on peak heating load and degree days.

program has been selected as the baseline of the comparison. The objective was to verify the accuracy of BLAST against two housing units whose performances have been monitored accurately. In the second phase, the candidate programs will be applied to a series of test cases and their predictions compared against those of BLAST. A wide variety of house types and climatic conditions will be used because the candidate programs involve the use of simplified input data and weather data, and therefore any one of them can be expected to predict the correct energy consumption for at least one house type and one climate. This report covers the first phase of the study, and describes the investigation into the accuracy of the BLAST program.

2.1 The BLAST Computer Program

The BLAST computer program was developed by the U. S. Army Construction Engineering Research Laboratory under the sponsorship of the Air Force Engineering and Services Center, Tyndall Air Force Base, Florida, and the Department of the Army, Office of the Chief of Engineers, Washington, D.C. After its original release in December 1977, it has been continually extended and refined. The most recent edition, Version 3.0, allows the use of schedules which vary hourly, daily and weekly and is capable of simulating a wide range of building features, such as natural ventilation, daylighting and Trombe walls. BLAST is particularly useful in its simulation of gains due to solar radiation because it takes the building thermal mass and transient effects into account. BLAST provides an in-depth hour-by-hour simulation of building thermal performance and energy consumption.

The BLAST computer program consists of three subprograms - the space heating and cooling loads prediction program which computes hourly space loads based on user input and hourly weather data, the air distribution system simulation program which uses the computed space loads and user inputs to calculate energy demands, and the central plant simulation program which simulates boilers, chillers, on site power generating equipment and solar energy systems and computes annual energy consumption and life cycle costs. For the purposes of this study, only the space loads prediction program was applicable since the two housing units selected were electrically heated and therefore did not have a complex air distribution system or central plant. The air distribution system simulation program and the central plant simulation program are primarily applicable to large commercial or industrial buildings, not residential housing units. Therefore, only the program space loads prediction program will be needed in the second phase of this project, and only this part of BLAST has been verified.

The most important aspect of the space loads prediction subprogram is the room heat balance. BLAST performs a complete radiant, convective and conductive heat balance for each surface of each zone and a heat balance on the room air, for each hour of the simulation. This includes transmission loads, solar loads, internal heat gains, infiltration loads and the temperature control strategy used to maintain space temperature. Some other important features of the space loads prediction are:

a) Response factors and conduction transfer functions are calculated for all zone surfaces. This accounts for transient heat conduction through walls and for heat storage in rooms.

b) The shaded and sunlit areas of all exterior surfaces shaded by attached or detached shadowcasting surfaces are calculated.

c) The solar flux transmitted through windows with or without interior shades is calculated.

d) The program accounts for the effects of both outside and inside surface solar absorptivities.

e) As part of the room heat balance, shape factors are used to calculate radiant heat transfer between zone surfaces. The radiant interchanges between exterior surfaces and the earth and sky are also calculated.

f) The effects of surface roughness and hourly variations in windspeed on outside wall convective heat transfer coefficients are also accounted for.

g) The inside surface convective heat transfer coefficient for ceilings, roofs and floors is adjusted by BLAST, depending on whether the surfaces are hotter or colder than the room air.

h) The program accounts for temperature differences between a zone and an unheated space (such as an attic or a crawl space) by actually simulating the unheated space.

i) The program calculates heat flow between zones with different temperatures.

j) Room temperature control strategies may be specified so that different strategies can be used for different hours of the day and different days during the week.

k) Radiant, convective and latent fractions of heat from people, lights and equipment are allocated to the air or surfaces receiving them. These internal gains may also be scheduled differently for each hour of the day and each day of the week.

l) The program simulates the effect of outside air-controlled baseboard heating controlled by outdoor air temperature.

m) The effects of windspeed, temperature and time of day on zone infiltration are taken into account.

n) Surfaces may be of arbitrary shapes (three and four-sided), and may be at any tilt or azimuth.

The BLAST computer program performs an in-depth simulation of building thermal performance based on the fundamental equations of thermodynamics and heat transfer. It has been extensively used and tested, and was therefore selected for testing to determine its suitability as the base program for this project.

2.2 Selection of Residential Housing Units

To adequately verify that the BLAST computer program could be used as a baseline for comparison, it was necessary to compare its prediction with the monitored performance of buildings similar to the ones to be used in the second phase of the study.

For complete confidence in results, the space temperatures and energy consumptions had to be compared on an hourly, daily, monthly and annual basis. Also, to verify the accuracy of BLAST for various types of house construction, a minimum of two houses (one energy efficient and one with standard construction) were required. Therefore, the problem was to locate two houses whose exact construction and details of operation were known, and which had been monitored on an hourly basis for a minimum of one year. Since life style can have an unquantifiable effect on energy consumption, it was also preferable that the houses be vacant, and have quantifiable internal gains.

It was found that the University of Alberta's Department of Mechanical Engineering had designed and constructed six demonstration houses for the purpose of thermal testing. Monitored data, on a hourly basis, was available for two of these houses. One house was constructed to be representative of the bulk of the housing stock in Canada, and one house was constructed to be highly energy efficient. The houses were vacant, and all internal gains were known. Also available for these two houses were data on the air change rate. Therefore, it was determined that comparing BLAST predictions with the monitored data of these two houses would be a good test of the BLAST computer program.

2.3 Details of the Test Houses

The six demonstration houses were constructed on the University of Alberta farm, located about one mile south of the present city limits of Edmonton, Alberta. The houses were constructed in a single east-west row, with 3.05 m spacing between them. Each of the houses has a different energy conservation or heating strategy. The East and West faces of the houses are 6.71 m wide,

while the North and South faces are 7.32 m wide. Each house is one storey high, has a full basement and a small attic. Both the main floor and the basement have a ceiling height of 2.44 m, with the basement 1.83 m below grade and 0.61 m above grade. The roof consists of trusses, plywood exterior sheathing and asphalt shingles. All of the houses are electrically heated. The heating systems consist of a 7.5 kW capacity central electric furnace, with the warm air distributed via metal ductwork and a blower. The two houses modelled in this phase of the project were the standard house (module 5) and the energy efficient house (module 3). A summary of the component areas and overall thermal resistances is given in Table 2.1. Details of house construction and dimensions are given in Figures 2.1 to 2.7.

Since the comparison of BLAST predictions and monitored results involves an analysis of space temperature, each house was divided into three zones - the basement, the main floor and the attic. Actual space temperatures for each of these zones, as well as ambient temperature, windspeed and direction and solar radiation were monitored by the University of Alberta.

2.3.1. Temperature Control Profiles

Temperature control strategies were based on site measurements, and are as follows:

a) Standard House

i) January 1 to April 7 and April 23 to December 31: heating comes on when module temperature is 20.3 C and shuts off when module temperature is 20.8 C.

ii) April 8 to April 22: heating comes on when module temperature is 19.8 C and shuts off when module temperature is 20.4 C.

TABLE 2.1

SUMMARY OF COMPONENT AREAS
AND THERMAL RESISTANCES

		STANDARD MODULE (#5)		ENERGY EFFICIENT MODULE (#3)	
		Area (m^2)	Overall Thermal Resistance (m^2K/W)	Area (m^2)	Overall Thermal Resistance (m^2K/W)
Ceiling		49.1	2.49	49.1	14.49
Main Walls	North	15.9	1.85	17.8	7.41
	East	12.5	1.85	13.3	7.41
	South	17.8	1.85	12.3	7.41
	West	14.4	1.85	16.3	7.41
Windows	North	1.9+	0.32	00.0	----
	East	2.0'	0.32	1.2'	0.32
	South	0.0	0.00	5.5+	0.32
	West	2.0'	0.32	00.0	----
Door (located on East Face)		1.9	1.99	1.9	1.99
Above Grade Foundation	North	4.5	2.07	4.5	3.83
	East	4.1	2.07	4.1	3.83
	South	4.5	2.07	4.5	3.83
	West	4.1	2.07	4.1	3.83
Below Grade Foundation	North	13.4	0.81	13.4	4.00
	East	12.3	0.81	12.3	4.00
	South	13.4	0.81	12.3	4.00
	West	12.3	0.81	12.3	4.00
Slab Floor*		49.1	0.38	49.1	0.38

* Overall thermal resistance includes .305m of dirt on the outside of the below grade components.

\+ Double glazed sealed windows.

' Double Glazed opening windows.

FIGURE 2.1
PLAN VIEW - STANDARD AND ENERGY EFFICIENT

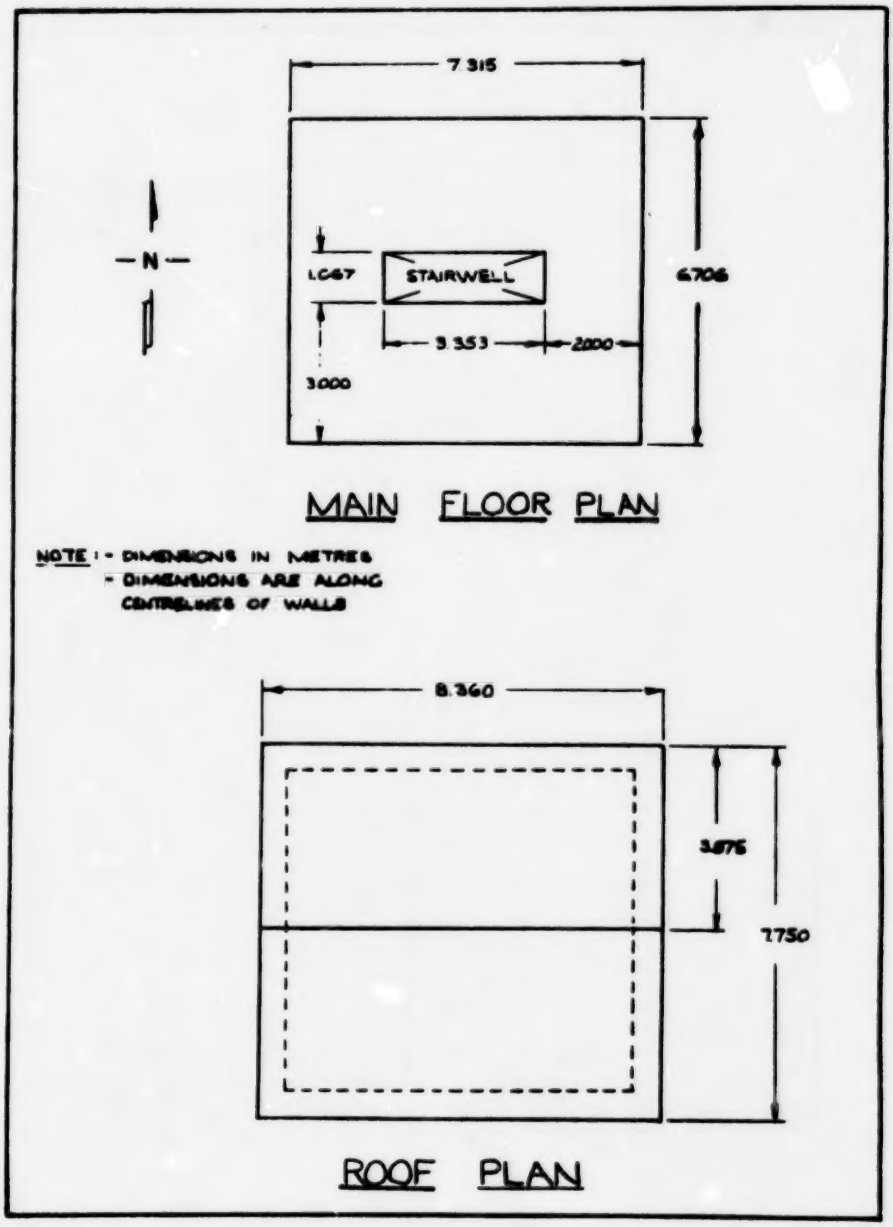


FIGURE 2.2
NORTH AND WEST ELEVATIONS - STANDARD

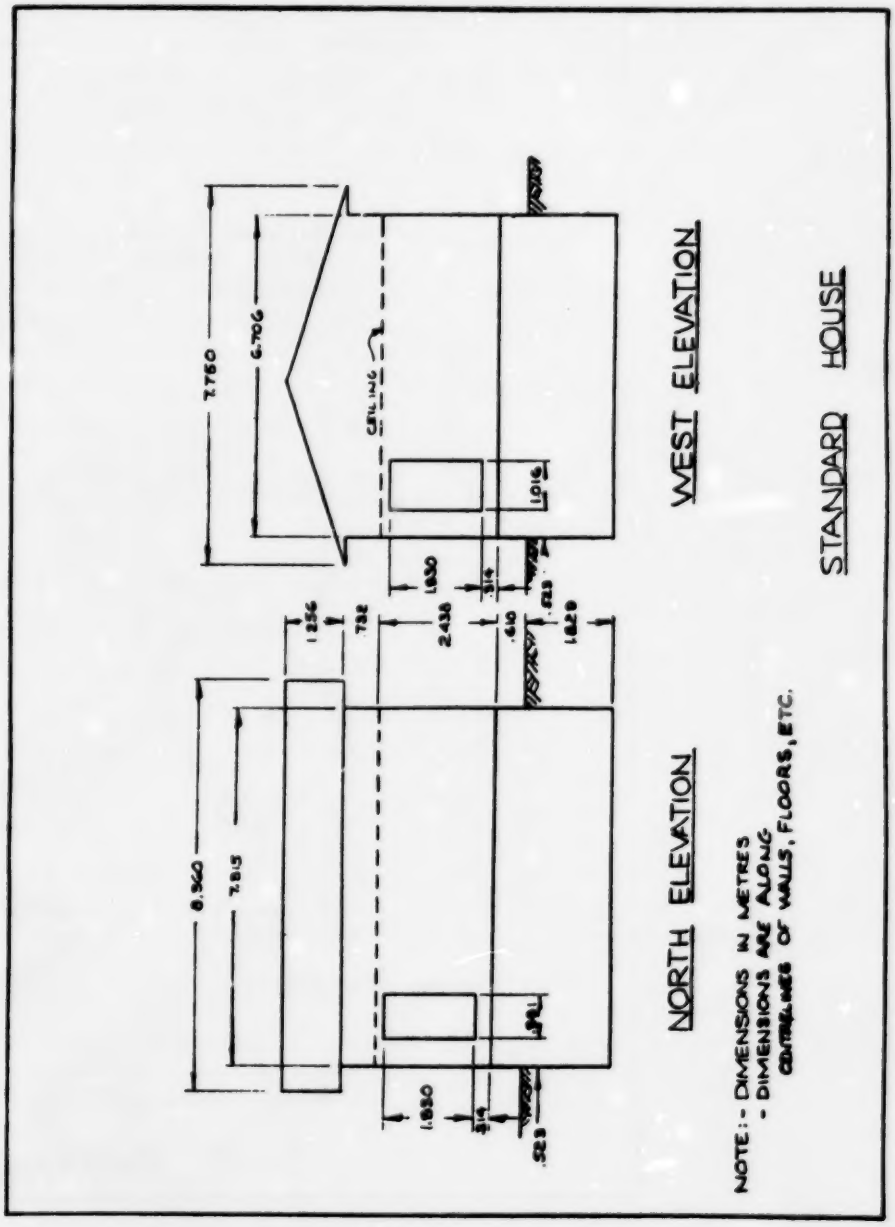


FIGURE 2.3
SOUTH AND EAST ELEVATIONS - STANDARD

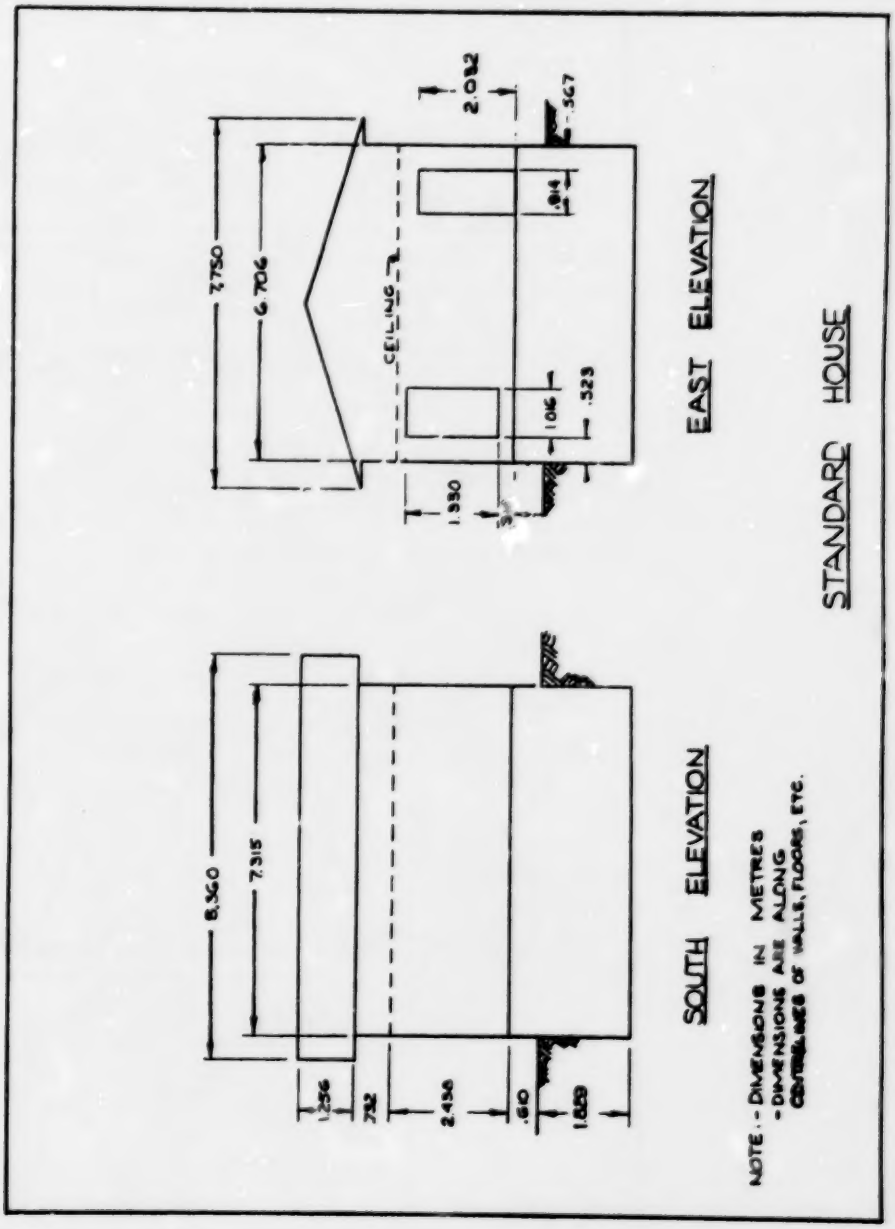


FIGURE 2.4
CROSS-SECTION - STANDARD

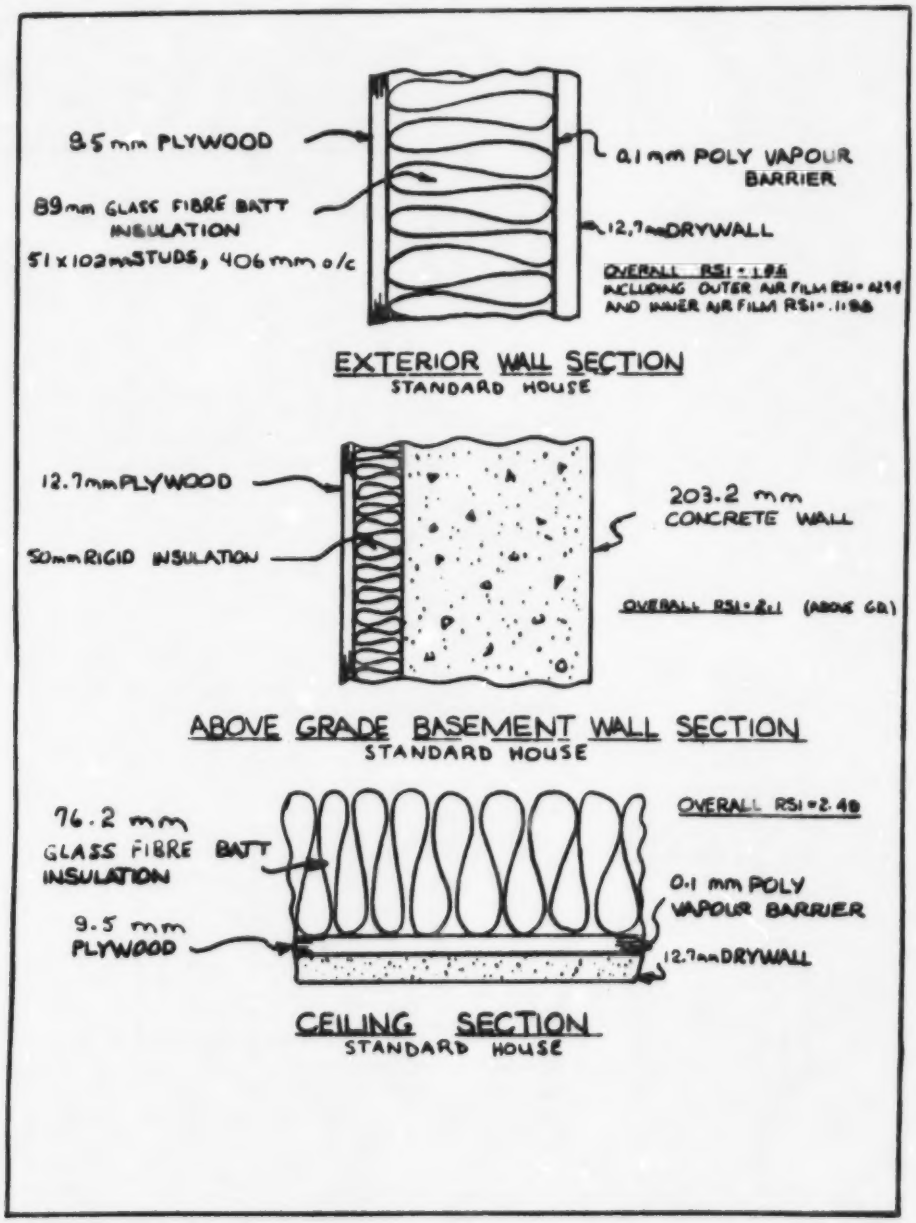

9.5 mm PLYWOOD
89 mm GLASS FIBRE BATT INSULATION
51 x 102 mm STUDS, 406 mm o/c
0.1 mm POLY VAPOUR BARRIER
12.7 mm DRYWALL
OVERALL RSI = 1.94
INCLUDING OUTER AIR FILM RSI = 0.29
AND INNER AIR FILM RSI = 0.11
EXTERIOR WALL SECTION
STANDARD HOUSE
12.7 mm PLYWOOD
50 mm RIGID INSULATION
203.2 mm CONCRETE WALL
OVERALL RSI = 2.11 (ABOVE GR)
ABOVE GRADE BASEMENT WALL SECTION
STANDARD HOUSE
76.2 mm GLASS FIBRE BATT INSULATION
9.5 mm PLYWOOD
OVERALL RSI = 2.48
0.1 mm POLY VAPOUR BARRIER
12.7 mm DRYWALL
CEILING SECTION
STANDARD HOUSE

FIGURE 2.5
NORTH AND WEST ELEVATIONS - ENERGY EFFICIENT

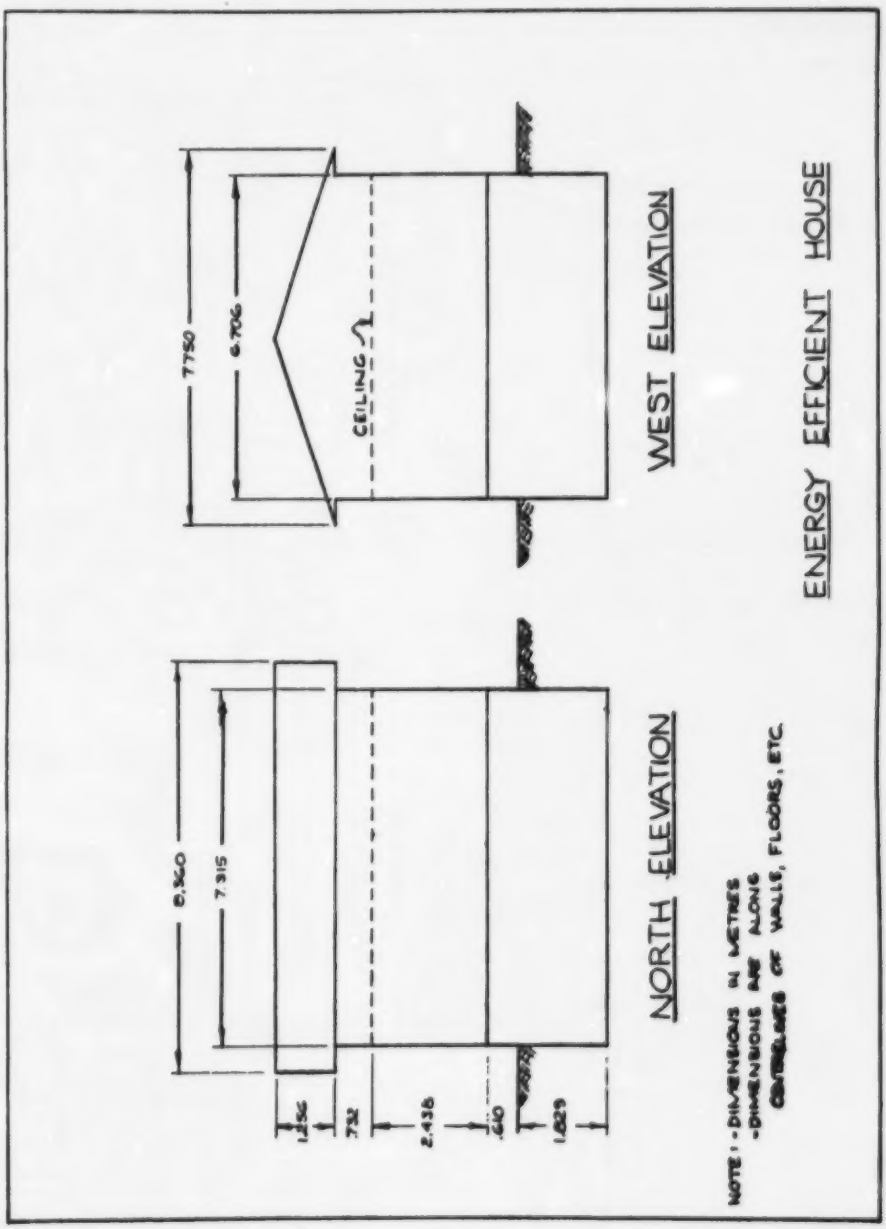


FIGURE 2.6
SOUTH AND EAST ELEVATIONS - ENERGY EFFICIENT

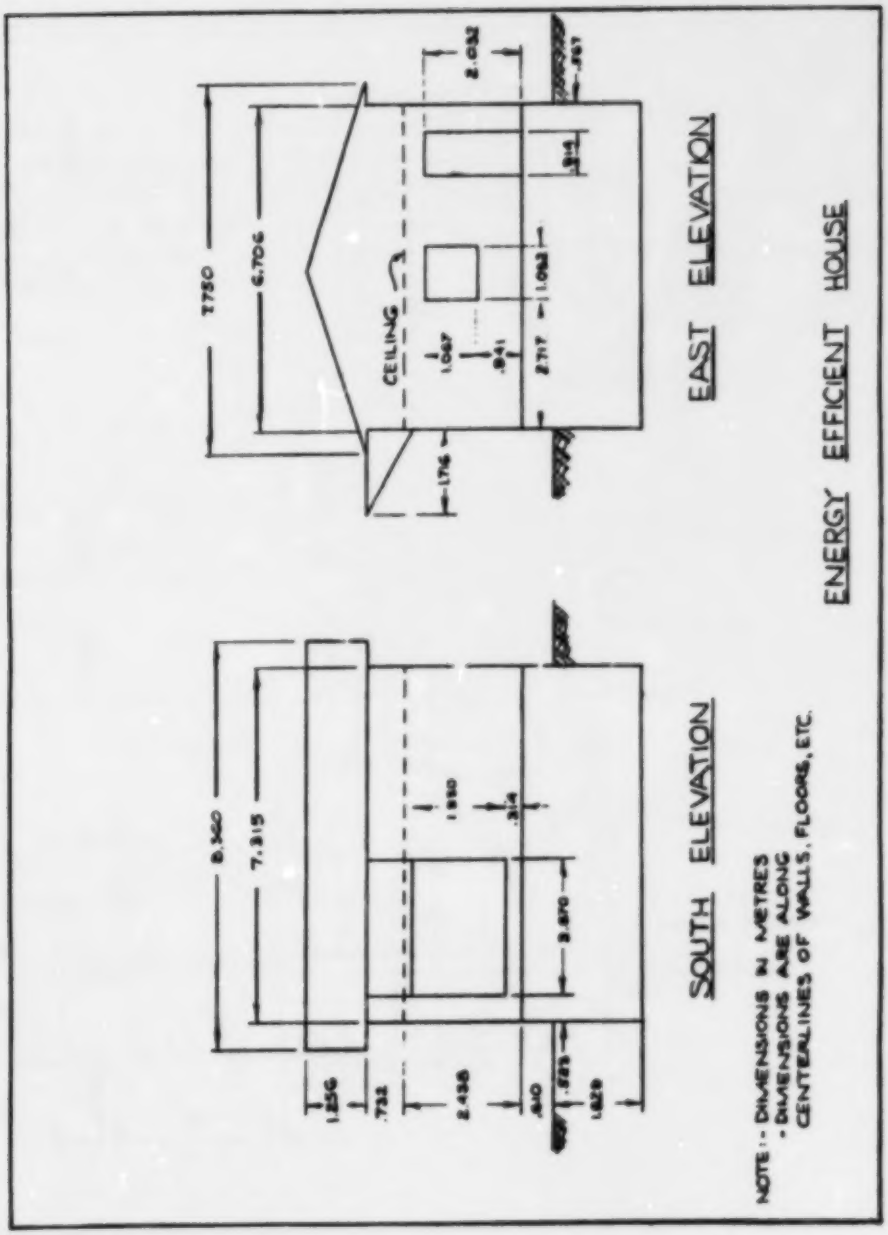
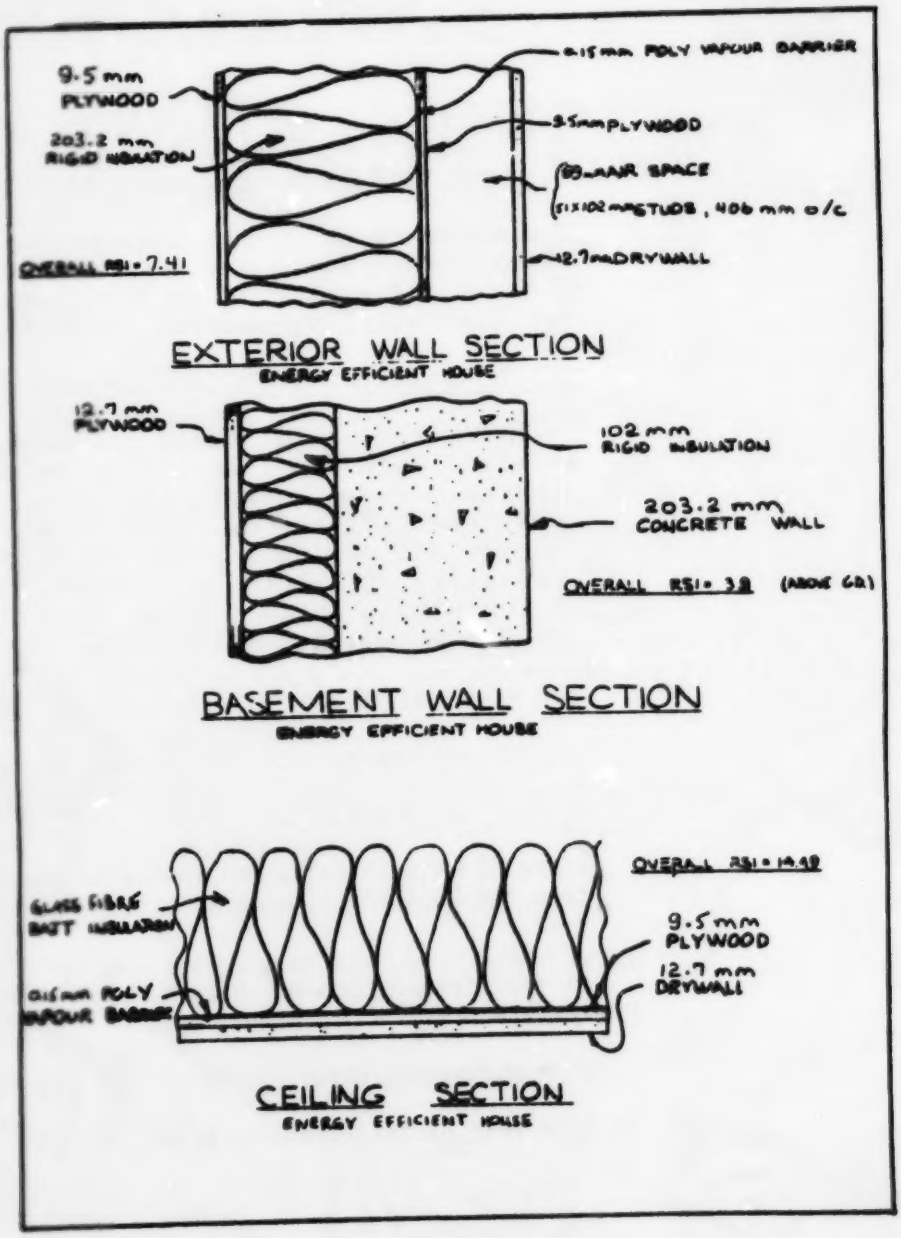


FIGURE 2.7
CROSS-SECTION - ENERGY EFFICIENT



b) Energy Efficient House

i) January 1 to April 7 and May 18 to December 31: heating comes on when module temperature is 20.5 C and shuts off when module temperature is 21 C.

ii) April 8 to May 17: heating comes on when module temperature is 19.8 C and shuts off when module temperature is 20.4 C.

The above temperatures were measured on the main floor. The heated air is directed to the main floor and distributed to the basement (through the stairwell) by natural convection.

2.3.2 Infiltration

Infiltration correlations for each of the houses modelled were supplied by the University of Alberta. These correlations were based on 500 measurements taken during December 1981 and January and February 1982, and according to the University of Alberta are within ten percent of the actual infiltration. The correlation for the standard module is:

$$I_{se} = (1.989 \times 10^{-5} \Delta T + 4.494 \times 10^{-5} W^2)^{\frac{1}{2}}$$

and for the energy efficient module is

$$I_{se} = (1.24 \times 10^{-6} \Delta T + 7.643 \times 10^{-6} W^2)^{\frac{1}{2}}$$

where SE = South-East, and indicates the wind is from the South-East, with an allowable range of $\pm 22^{0}$.

ΔT = difference between indoor and outdoor temperatures, C.

W = windspeed, m/s.

I = rate of infiltration, m^3/s.

When the wind direction is other than South-East, the rate of infiltration is:

$$I = 0.8\ I_{se}$$

The infiltration correlations used in the BLAST simulation were based on hourly rates of infiltration obtained using the above equations. The form of the BLAST correlation for infiltration is:

$$I_{act} = I_{max}\ F_{sch}\ (A + B\ (T_i - T_{odb}) + CW + DW^2)$$

where

I_{act} = the actual rate of infiltration, m^3/s

I_{max} = the maximum rate of infiltration specified by the user, m^3/s

F_{sch} = fractional infiltration schedule specified by the user, which may be used to account for variations in frequency of door openings or in large buildings to account for hours that the building is pressurized. In this analysis F_{sch} was set to equal 1.0.

T_i = indoor temperature, C

T_{odb} = outdoor dry bulb temperature, C

W = windspeed, m/s

A, B, C, D = user-specified coefficients

The correlation used for the standard house is

$$I_{act} = .0148\ (.0557\ (T_i - T_{odb}) + .0231\ W^2)$$

and for the energy efficient module is

$$I_{act} = .00422\ (.0241\ (T_i - T_{odb}) + .4919\ W)$$

2.3.3 Internal Heat Gains

Although the modules were unoccupied, there were some internal gains. These gains appeared in the monitored hourly power consumption during the summer months. Since there are virtually no building heating loads during the summer months, the recorded data were used to determine a rate of internal gains which would be extrapolated and used in the BLAST simulation. Internal heat gains were set at 540 W for the standard module and 390 W for the energy efficient module, with one-third of the gains located in the basement and two-thirds of the gains located on the main floor.

2.3.4 Ground Temperatures

a) Development of Ground Temperature Values

BLAST models below grade losses through building envelope components in the same way as it models above grade losses: by simulating the transient heat transfer through the component on an hour-by-hour basis. However, the external conditions for the above grade heat loss calculation are more easily obtained than those for the below grade calculation. Above grade, the hour-by-hour weather data allow the outside surface temperature to be calculated. Below grade, it is necessary to know the monthly average temperature at some plane in the soil and the thermal properties of the soil between that plane and the basement wall in order to solve for the heat transfer through the wall. The soil between the plane where the temperature is specified and the basement wall itself is treated as a component of the wall in the analysis.

The BLAST analysis of heat loss through building components is one dimensional, since it would not be practical to simulate three dimensional transient heat transfer on an hour-by-hour basis. The user can increase the precision of this analysis by splitting the basement into several walls, each having a different depth below grade and therefore a different monthly average external

temperature, provided there is adequate information to justify this level of detail.

In the present case, no data on soil temperature or soil thermal properties had been obtained at either of the test houses. However, soil temperatures had been measured at 30 cm. from the wall and at three different depths on two neighbouring houses. These soil temperatures were available for only the last four months of the test year. The basement insulation was not similar to that in the two test houses, so the measured temperatures could not be used directly.

To use these measured temperatures to estimate the temperatures required as BLAST input, the following technique was applied.

First, monthly heat losses were calculated for each segment of the basement wall, using the technique developed by Mitalas("Basement Heat Loss Studies at DBR/NRC" by G. P. Mitalas, DBR Paper # 1045, 1982).

This was done for each of the houses for which measured soil temperatures were available. Then, the measured soil temperatures were interpolated to find the mean temperature at 30 cm from the wall in the center of each segment. These temperatures were then corrected to apply to the two modules which were to be compared with BLAST by using the equation:

$$\frac{Q_{m,1}}{Q_{m,2}} = \frac{U_1}{U_2} \frac{(T_i - T_{g,1})}{(T_i - T_{g,2})}$$

Where Q_m = heat loss predicted by the Mitalas method

U = overall conductance, from inside the basement to a point 30 cm into the soil

T_i = basement air temperature

T_g = ground temperature 30 cm into the soil

1,2 = subscripts indicating the module for which soil temperatures were measured and the one for which they are needed.

The soil temperatures for the basement wall and floor segments were then averaged (weighted according to their conductance x area products) to find a single soil temperature for use in BLAST for each of the four months for which temperature data was measured.

This approach provided no data for the first eight months of the year. As a first approximation, the four temperatures which were estimated by this means (13,12,11,10 C) were extended to an annual profile (9,9,9,9,10,11,13, 13,13,12,11,10) by estimation. This estimate was intended only to permit trial runs of the program until further soil temperature data for the following year could be obtained from the University of Alberta. However, this additional data was not forthcoming, so a set of BLAST annual simulations was carried out using the estimated data.

When the BLAST simulations were carried out, the results indicated that this soil temperature estimate was not adequate. Soil temperature is the only value which is input to BLAST on a monthly basis, so an offset error which is constant during each month is an indication of an error in this variable. The variation of the error from month to month indicated that our temperature profile had its maximum and minimum too early in the year (on August 15 and March 1 respectively). Therefore a search was made for soil temperature data from the general area which could be used to improve the estimate.

It was found that soil temperatures at a depth of 3 m were recorded at Vegreville, Alberta, 100 km from the test site. During the four months of our temperature estimate, the average temperature measured at Vegreville was 4.4 C below that estimated at our test site. Therefore, a new temperature profile was created by adding 4.4 C to each of the monthly temperatures recorded at Vegreville. The resulting data were rounded off to the nearest degree Celcius.

The monthly ground temperatures were then (9,8,6,6,8,9,10,11,12,12,12,11). This set of ground temperatures average 1.25 C lower than those previously estimated.

b) Discussion of Significance of Ground Temperature Data

This method of estimating ground temperatures was obviously quite arbitrary. It is unlikely that a measurement of the average ground temperature would have yielded this set of numbers. It is also unlikely that the soil thermal conductivity value which we assumed for this analysis (K = 1.5 W/m C) was an accurate estimate of the conductivities of the soils in the 30 cm slabs surrounding the basement walls. It would have been desirable to have accurately measured soil temperatures and thermal conductivities, but they were not available. However, considering the objectives of the present study, the use of these estimates was not a major problem.

The purpose of this project was to verify that the portion of the BLAST program used to model the test modules was working correctly, and that there were no mistakes in the input data which had been prepared to describe these test modules. The verification of BLAST and of the input data was based on hour-by-hour comparison of the power consumption and temperature predictions of the program with the measured data. This verification could not, however, detect small errors in the many variables used to describe the test modules. In addition to soil temperature and conductivity, these variables included the thermal conductivity, density, specific heat, infrared absorbtance and solar absorbtance of each of the other materials used in the house, the thickness and area of each component, optical properties of window glass, power consumption of motors, air flow rates of fans, infiltration coefficients, thermostat set points, weather parameters, shutter operating schedules, and many others. Obviously, all these

values were in error. The good agreement between the measured and predicted temperatures and power consumptions in the present study simply proves that the effects of these various errors have cancelled one another reasonably well.

At any rate, these many errors in the description of the test house had no effect on the ultimate objective of the present study; to use BLAST to verify the performance of several simpler, more approximate programs. This verification did not depend on the accuracy with which the University of Alberta test modules were described. The question put to BLAST and to each of the other programs to be compared with it was not "What is the energy consumption of a real house in Edmonton which we think has approximately the following description, and which is subject to weather and soil conditions which we don't know exactly, but which are roughly the same as those measured at three weather stations near the site?" Rather, each of the programs has been asked, "What is the energy consumption of the following idealised house, having exactly the physical description and thermal properties listed here, and subject to exactly the weather and soil conditions listed?" Thus the errors in soil temperature and other input variables, while they have decreased the precision of the verification of BLAST, have had no effect whatever on the ultimate objective of the project, the verification of the simple programs.

3.1 Methodology

Verification of the BLAST computer program against monitored data was conducted in two steps. The two University of Alberta test houses were first simulated by BLAST under steady-state conditions. This was accomplished by defining design days that had constant ambient conditions and no solar radiation. These results were then verified against hand calculations. The second step of the verification was an annual simulation using BLAST and recorded hourly weather data. These results were verified against data monitored on an hourly basis.

3.2 The Steady-State Analysis

Precise agreement cannot be expected between a steady-state computer simulation and a manual calculation. Thermal radiation is an important heat transfer mode in buildings, but in manual calculations radiation and convection to an exterior wall from the rest of the room are usually characterized by a single heat transfer coefficient which combines both effects. However, BLAST simulates the radiant interchange between all the surfaces within the cavity, as well as the convection from the air and the conduction from the air and the conduction from within each wall. In the present case, the main floor and the basement each have ten heat transfer surfaces. Since the floor between them also transfers heat, twenty-two equations with twenty-two unknowns must be solved simultaneously. To carry out a manual calculation which would agree precisely with BLAST, it would be necessary to solve the same radiant interchange problem. This is impracticable. It is also unnecessary in most cases, since the thermal resistance of a typical wall is much higher than that between the wall surface and the room air (especially in the case of the energy efficient module), and since convection is usually at least as important as radiation as a heat transfer mechanism. Therefore, a manual computation based

on a reasonable combined heat transfer coefficient will provide a heat flux which is close to the BLAST prediction. This approach is less accurate for window heat fluxes, but the impact of the error is still small if the window area is small (which it is in the standard module).

The only surface for which the approximation of the manual steady-state calculation is not accurate enough to provide a check of the BLAST heat flux calculation is the basement floor. Since it is uninsulated, and since the convective heat transfer coefficient is very low for downflow of heat, radiation is the dominant mode of heat transfer. Therefore, the heat flux is sensitive to the temperatures of all the surfaces and cannot be determined by the use of a "standard" value of a combined heat transfer coefficient.

Because of this problem, the following approach was taken to checking BLAST's steady-state energy consumption prediction for the energy efficient and standard house models.

First, using BLAST, each house was modelled as if there was no air mixing between the main floor and the basement. Instead, the basement temperature was maintained by a thermostatically controlled heater. This provided a prediction of the energy consumption of the main floor and of the basement separately.

Then, the below grade portion of the basement was modelled using BLAST. These BLAST predictions were then combined with hand calculations for the above grade portion of the houses to obtain the energy consumption of the main floor and of the basement.

The calculated energy consumption was then compared to the BLAST prediction of energy consumption for each house. A comparison for the standard module is given in Table 3.1 and

TABLE 3.1

STEADY STATE ANALYSIS

ENERGY CONSUMPTION FOR ONE DAY

STANDARD MODULE (#5)

	HAND CALCULATION* kWh/d	BLAST PREDICTION kWh/d
Main Floor	66.20	60.59
Basement	40.86	39.89
Total	107.06	100.48

*Hand calculation based on BLAST prediction only of the below-grade energy consumption, combined with hand calculation of above grade energy consumption.

a comparison for the energy efficient module is given in Table 3.2. These comparisons indicate a good correlation between the hand calculations and the BLAST predictions.

It should be noted that in all the steady-state analyses carried out, all temperatures (ambient air, soil and thermostat settings) were 3 C above the actual temperatures because this resulted in a faster approach to the steady-state condition in the BLAST predictions, and therefore required less computer time.

3.3 The Annual Simulation

The annual simulation consisted of running BLAST with recorded hourly weather data. It is more efficient to use one full calendar year of weather data with BLAST than weather data over a particular heating season. Therefore, since the University of Alberta only had one full calendar year of monitored results, the simulation was performed for that year - 1981. Hourly values of climatic conditions recorded on the site were available, but they were not in a format which could be adapted for BLAST analysis. The recorded weather information was also not as complete as BLAST requires, and would have had to be supplemented even if it was in the correct format. Therefore, the hourly weather data used for the BLAST simulation was recorded at the Edmonton International Airport and was supplied by the Atmospheric Environment Service of Canada (AES). AES weather data are in a format that can be used by BLAST. It is important to note that the AES weather data were recorded several miles south of the University of Alberta farm, and therefore deviated somewhat from the data recorded on the site.

TABLE 3.2

STEADY STATE ANALYSIS

ENERGY CONSUMPTION FOR ONE DAY

ENERGY EFFICIENT MODULE (#3)

	HAND CALCULATION* kWh/d	BLAST PREDICTION kWh/d
Main Floor	28.85	23.38
Basement	37.60	37.63
Total	66.45	61.01

*Hand calculation based on BLAST prediction only of the below-grade energy consumption, combined with hand calculation of above grade energy consumption.

3.3.1 Weather Data Comparison

Since verification of BLAST for use as a baseline involves hourly, daily and annual comparisons, the weather data were also examined on this basis. Tables 3.3 to 3.5 compare hourly weather data recorded by AES and at the site on December 1 to 3, 1981. This period was selected for close examination because at this time the houses have typical winter heating load requirements and because the monitored data (energy consumption, space temperatures and site climatic conditions) is complete. Tables 3.3 to 3.5 compare hourly values of total horizontal radiation and the daily total, hourly values of ambient temperature and windspeed and their daily averages. These tables show that the total horizontal radiation and ambient temperatures used by BLAST and recorded on site have similar profiles. Hourly values of windspeed deviate somewhat more than the above, but the daily average indicates better agreement.

It should be noted that at various times throughout 1981 the hourly data were not recorded. This may have been due to equipment repair, power failure or any number of other causes. Therefore, the climatic conditions recorded at the site could only be compared to the AES data on an hourly and on a daily basis for selected periods. However, the annual energy consumption of each house was monitored separately with an energy meter, and consumptions were recorded on a monthly basis.

The weather data used in BLAST were also compared to site data on a daily basis. Three-day periods of uninterupted site data were selected for various times of the year. These data were compared to AES weather data on a daily basis, and are illustrated in Tables 3.6 and 3.7 The daily total horizontal radiation, average windspeed and average ambient temperature (shown in Table 3.6) recorded at the site are similar to those supplied by AES. The mean high and

TABLE 3.3

COMPARISON OF HOURLY WEATHER DATA
SITE MEASUREMENTS VS. BLAST

1981 - 12 - 01

HOUR	TOTAL HORIZONTAL RADIATION (Wh/m²)		AMBIENT TEMPERATURE (C)		WINDSPEED (m/s)	
	SITE	BLAST	SITE	BLAST	SITE	BLAST
1	0	0	-4.4	-5.3	6.9	7.8
2	0	0	-3.7	-4.1	7.4	8.6
3	.1	0	-2.9	-4.0	6.4	7.2
4	.2	0	-2.4	-3.4	4.8	6.7
5	.3	0	-2.2	-2.9	2.1	3.6
6	.2	0	-2.2	-2.9	2.0	2.5
7	.5	0	-1.7	-2.5	1.1	1.7
8	.3	0	-1.6	-2.5	1.6	1.1
9	4.7	1.4	-1.4	-2.1	0.3	1.9
10	24.4	29.4	-0.5	-1.5	2.6	0.0
11	58.3	64.6	0.9	-1.4	4.6	1.9
12	73.0	97.5	2.6	0.8	4.1	5.6
13	121.2	176.6	4.6	2.9	4.8	7.8
14	169.9	217.0	5.6	6.0	8.3	12.8
15	121.6	167.4	5.4	6.0	8.6	10.8
16	34.1	78.2	4.8	5.9	9.4	16.4
17	0	1.0	3.0	3.2	6.1	6.7
18	0	0	-0.9	0.8	3.7	3.1
19	0	0	-4.1	-2.3	3.5	4.7
20	0	0	-3.4	-0.9	4.0	4.2
21	0	0	-4.8	-2.4	4.0	4.2
22	0	0	-5.2	-5.3	4.6	3.6
23	0	0	-6.5	-4.5	2.8	3.1
24	0	0	-6.7	-7.3	2.6	5.6
	608.8	833.1	-1.2*	-1.2*	4.4*	5.5*

*AVERAGE

TABLE 3.4

COMPARISON OF HOURLY WEATHER DATA

SITE MEASUREMENTS VS. BLAST

1981 - 12 - 02

Hour	TOTAL HORIZONTAL Radiation (Wh/m²)		AMBIENT TEMPERATURE (C)		WINDSPEED (m/s)	
	SITE	BLAST	SITE	BLAST	SITE	BLAST
1	0	0	-8.5	-7.0	2.7	4.7
2	0	0	-8.0	-7.1	3.3	4.7
3	0	0	-6.7	-5.4	3.8	5.6
4	0	0	-5.4	-5.3	4.4	4.2
5	0	0	-3.8	-5.6	4.2	4.2
6	0	0	-3.3	-3.6	4.0	5.6
7	0	0	-2.7	-3.0	3.3	6.1
8	0	0	-2.2	-2.4	2.5	4.2
9	3.5	1.3	-1.8	-3.6	2.7	1.7
10	34.5	28.4	-0.9	-2.3	1.5	2.5
11	61.4	128.2	0.7	-1.9	2.2	1.7
12	222.3	203.9	2.5	-0.7	6.5	3.1
13	162.5	193.4	4.5	3.3	9.3	9.7
14	199.3	139.5	4.5	3.4	7.4	7.8
15	56.5	65.4	3.8	4.0	7.5	8.3
16	14.9	22.0	3.0	3.6	9.3	11.9
17	0.7	0.2	2.7	2.9	11.0	11.9
18	0	0	2.1	2.9	10.6	11.4
19	0	0	1.7	1.4	11.8	11.9
20	0	0	1.2	1.5	12.5	11.9
21	0	0	0.6	1.0	10.3	12.8
22	0	0	0.1	0.3	9.6	13.9
23	0	0	-0.4	0.1	9.0	13.3
24	0	0	-0.9	-0.4	7.4	10.3
	755.6	782.3	-0.7*	-1.0*	6.5*	7.7*

*AVERAGE

TABLE 3.5

COMPARISON OF HOURLY WEATHER DATA
SITE MEASUREMENTS VS. BLAST

1981 - 12 - 03

HOUR	TOTAL HORIZONTAL RADIATION (Wh/m²)		AMBIENT TEMPERATURE (C)		WINDSPEED (m/s)	
	SITE	BLAST	SITE	BLAST	SITE	BLAST
1	0	0	-1.1	-1.0	6.5	8.6
2	0	0	-2.8	-1.3	4.9	7.2
3	0	0	-4.0	-4.7	3.7	2.5
4	0	0	-6.0	-5.4	2.8	3.1
5	0	0	-6.2	-6.8	3.4	3.1
6	0	0	-6.7	-5.2	3.2	4.2
7	0	0	-8.8	-5.5	3.6	5.3
8	0	0	-6.3	-6.1	3.4	5.3
9	11.5	2.4	-4.9	-4.0	4.0	6.1
10	88.3	69.6	-4.2	-5.0	4.0	5.6
11	168.6	162.8	-2.5	-3.5	5.0	5.3
12	218.7	222.4	-1.5	-2.4	5.0	6.7
13	228.3	243.5	-1.0	-1.1	4.3	6.1
14	181.7	224.3	-0.8	-0.5	3.3	5.6
15	121.0	163.7	-1.2	0.3	1.9	1.7
16	24.4	56.0	-3.6	-0.5	2.8	0.0
17	0	0.3	-7.1	-5.3	2.8	1.1
18	0	0	-8.0	-9.6	3.1	0.0
19	0	0	-9.1	-7.4	2.2	0.0
20	0	0	-11.9	-9.2	1.6	4.2
21	0	0	-11.7	-9.6	2.3	3.6
22	0	0	-12.1	-12.9	1.9	1.7
23	0	0	-11.1	-10.4	1.3	1.1
24	0	0	-10.2	-9.4	1.8	0.0
	1042.5	1145.0	-6.0*	-5.3*	3.3*	3.7*

*AVERAGE

TABLE 3.6

COMPARISON OF DAILY WEATHER DATA
SITE MEASUREMENTS VS. BLAST

	TOTAL HORIZONTAL RADIATION (Wh/m²)		AVERAGE WINDSPEED (m/s)		AVERAGE AMBIENT TEMPERATURE (C)	
	SITE	BLAST	SITE	BLAST	SITE	BLAST
JAN 1	1202	987	2.4	2.4	-12.1	-11.5
2	910	1014	3.4	3.1	-12.3	-11.9
3	948	1163	2.3	2.5	-11.2	-9.8
APR 9	1938	3173	3.0	4.2	0.7	1.2
10	4281	5311	2.5	3.5	0.6	1.4
11	714	899	4.0	5.4	-2.7	-2.7
SEP 5	4580	4715	1.7	2.3	11.6	11.6
6	4001	4924	2.7	3.8	13.0	13.7
7	5055	5361	2.8	3.0	15.6	16.8
DEC 1	609	833	4.4	5.5	-1.2	-1.2
2	776	782	6.5	7.7	-0.7	-1.0
3	1043	1145	3.3	3.7	-6.0	-5.3

TABLE 3.7

COMPARISON OF DAILY WEATHER DATA
SITE MEASUREMENTS VS. BLAST

		MEAN AMBIENT TEMPERATURE (C)		HIGH AMBIENT TEMPERATURE (C)		LOW AMBIENT TEMPERATURE (C)	
		SITE	BLAST	SITE	BLAST	SITE	BLAST
JAN	1	-12.0	-10.7	-7.6	-3.5	-16.4	-17.8
	2	-12.8	-11.1	-9.7	-5.7	-15.9	-16.4
	3	-10.4	-8.9	-3.7	0.0	-17.0	-17.8
APR	9	1.5	1.5	6.2	4.3	-3.2	-1.4
	10	1.1	1.7	8.0	8.2	-5.8	-4.8
	11	-3.7	-3.9	3.0	2.0	-10.3	-9.7
SEP	5	12.3	12.1	19.0	18.8	5.6	5.4
	6	12.9	13.0	20.4	21.6	5.4	4.3
	7	16.4	17.4	25.4	26.5	7.4	8.2
DEC	1	-0.6	-0.7	5.6	6.0	-6.7	-7.3
	2	-2.0	-1.6	4.5	4.0	-8.5	-7.1
	3	-6.5	-6.3	-0.8	0.3	-12.1	-12.9

low ambient temperatures recorded at the site (shown in Table 3.7) are also very similar to those supplied by AES. Taking mean values from Table 3.7, and assuming an interior temperature of 20 C, it can be shown that the resulting error is less than 5% over any three day period. Over longer periods the error would probably be even smaller. However, it is difficult to quantify the effects of the variations in the other weather parameters will have on the prediction of the house heating load. However, since the weather information supplied by AES are the best data available for the study, and since they were recorded in a similar microclimate (rural setting with no obstructions such as wind breaks or shading), it is reasonable to use the AES weather data for the simulation. A summary of AES data for Edmonton 1981 is given in Table 3.8.

3.3.2 Hourly Comparison

Space temperatures and power consumptions predicted by BLAST were compared to data monitored on site. As previously mentioned, site data were not recorded continuously, and could therefore only be compared for selected periods of time. In fact, the attic and basement space temperatures recorded on site were available only from September through December. However, the main floor space temperature was monitored for the full year. Figures 3.1 to 3.4 illustrate examples of hourly space temperature profiles for the attic and main floor in both the standard and energy efficient modules. Figures 3.5 to 3.8 illustrate examples of hourly total power consumption profiles. Although the BLAST prediction of space heating load was available, the site monitoring did not include space heating load. Therefore, total power consumption was compared. The graphs in Figures 3.1 to 3.8 indicate that the hourly space temperature and total energy consumption profiles predicted by BLAST correlate well with the site measurements. The peak energy demand for each house and the time of occurrence are given in Table 3.9. It should be noted that there were many anomalies in the recorded data, and it was therefore difficult to pick out the peak loads.

TABLE 3.8

SUMMARY OF AES WEATHER DATA
EDMONTON, ALBERTA
1981

	HEATING DEGREE DAYS	TOTAL HORIZONTAL RADIATION (Wh/m²)	MEAN AMBIENT TEMPERATURE (C)	HIGH AMBIENT TEMPERATURE (C)	LOW AMBIENT TEMPERATURE (C)
JAN	752.0	32,674	-5.9	5.9	-17.8
FEB	717.5	52,752	-7.3	9.3	-27.8
MAR	565.4	108,655	0.1	14.5	-18.4
APR	423.3	148,020	4.2	22.0	-13.2
MAY	227.7	155,806	11.0	25.0	-3.3
JUN	182.4	194,100	12.3	24.8	1.3
JUL	93.7	178,033	15.4	29.2	3.2
AUG	48.2	177,847	17.5	30.6	4.0
SEP	210.6	109.920	11.5	33.5	-0.5
OCT	461.2	68,634	3.5	19.0	-10.4
NOV	569.4	30,900	-0.6	16.1	-12.6
DEC	913.2	24,614	-11.1	6.0	-35.7
ANN	5,164.6	1,281,955			

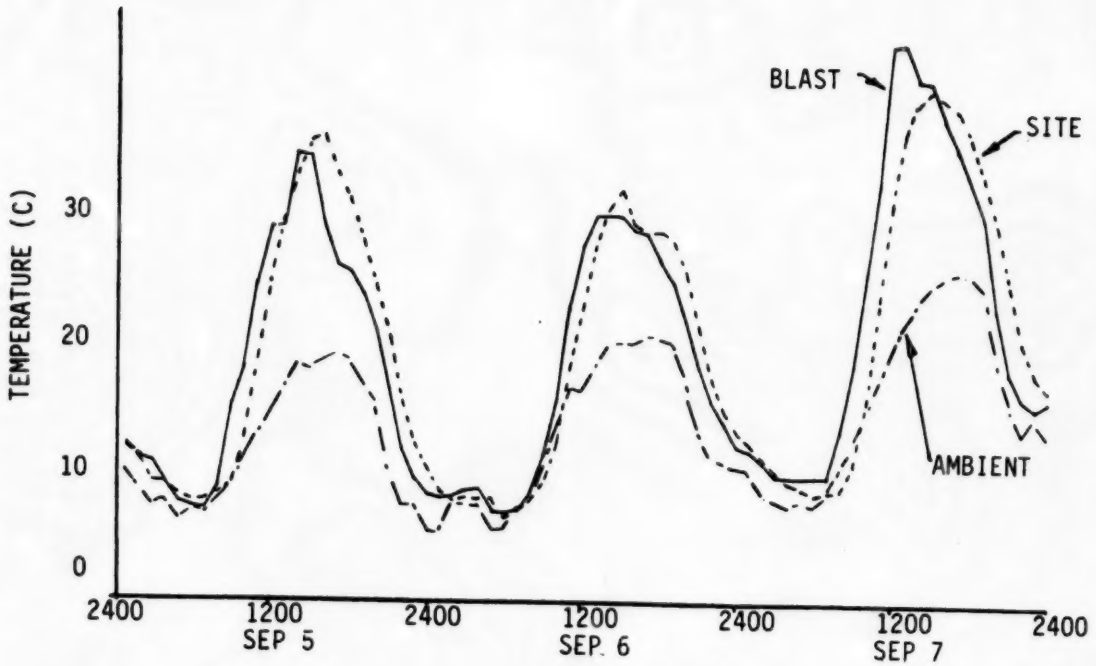


FIGURE 3.1

COMPARISON OF HOURLY SPACE TEMPERATURES
SITE MEASUREMENTS VS. BLAST
STANDARD HOUSE (#5) - ATTIC

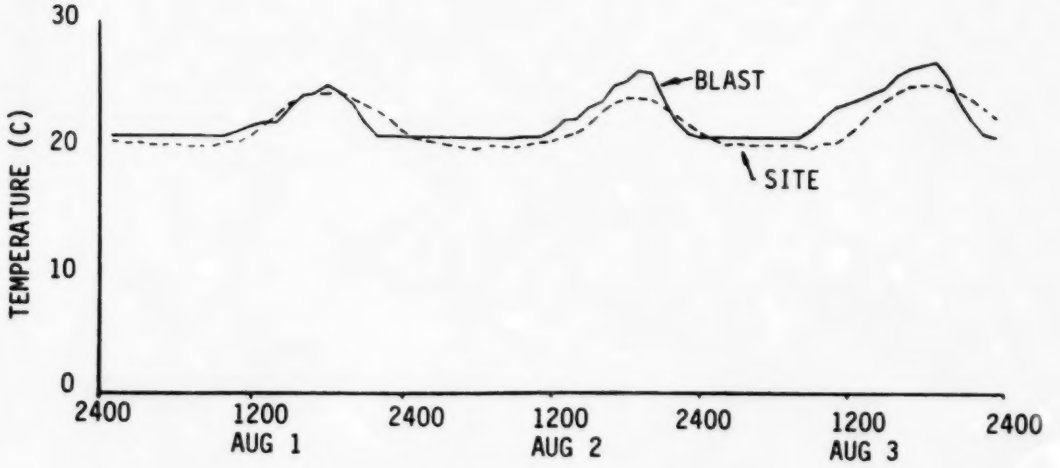


FIGURE 3.2

COMPARISON OF HOURLY SPACE TEMPERATURES
SITE MEASUREMENTS VS BLAST
STANDARD HOUSE (#5) - MAIN FLOOR

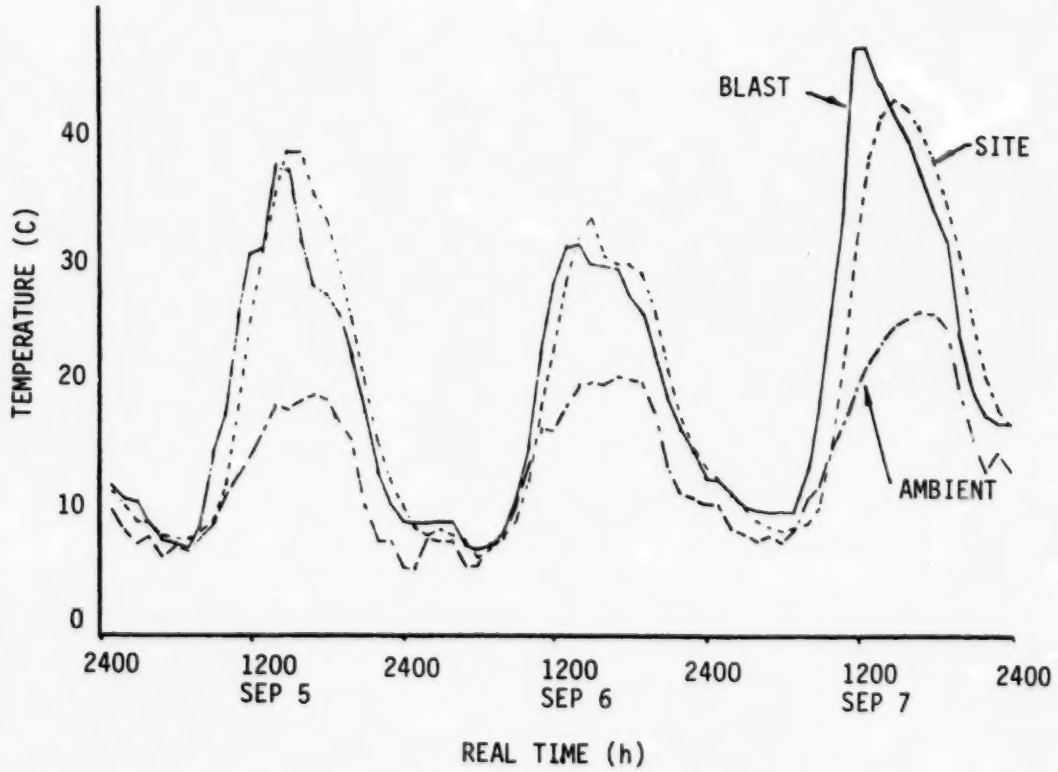


FIGURE 3.3

COMPARISON OF HOURLY SPACE TEMPERATURES
SITE MEASUREMENTS VS BLAST
ENERGY EFFICIENT HOUSE (#3) - ATTIC

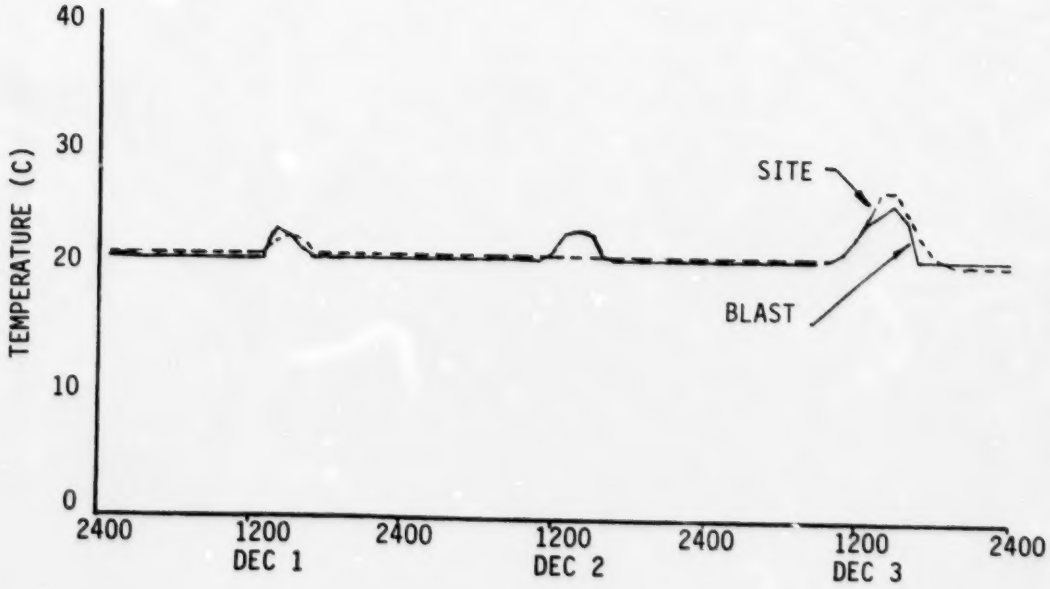


FIGURE 3.4

COMPARISON OF HOURLY SPACE TEMPERATURES
SITE MEASUREMENTS VS BLAST
ENERGY EFFICIENT HOUSE (#3) - MAIN FLOOR

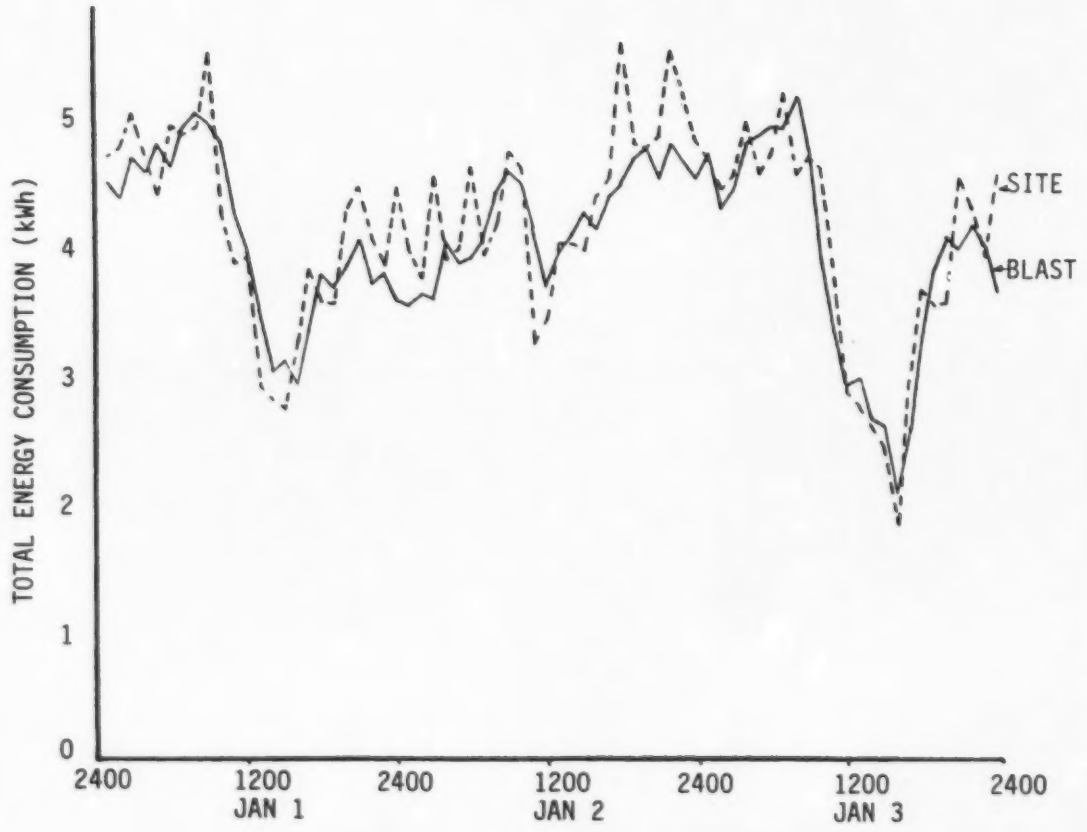


FIGURE 3.5

COMPARISON OF HOURLY TOTAL ENERGY CONSUMPTION
SITE MEASUREMENTS VS BLAST
STANDARD HOUSE (#5)

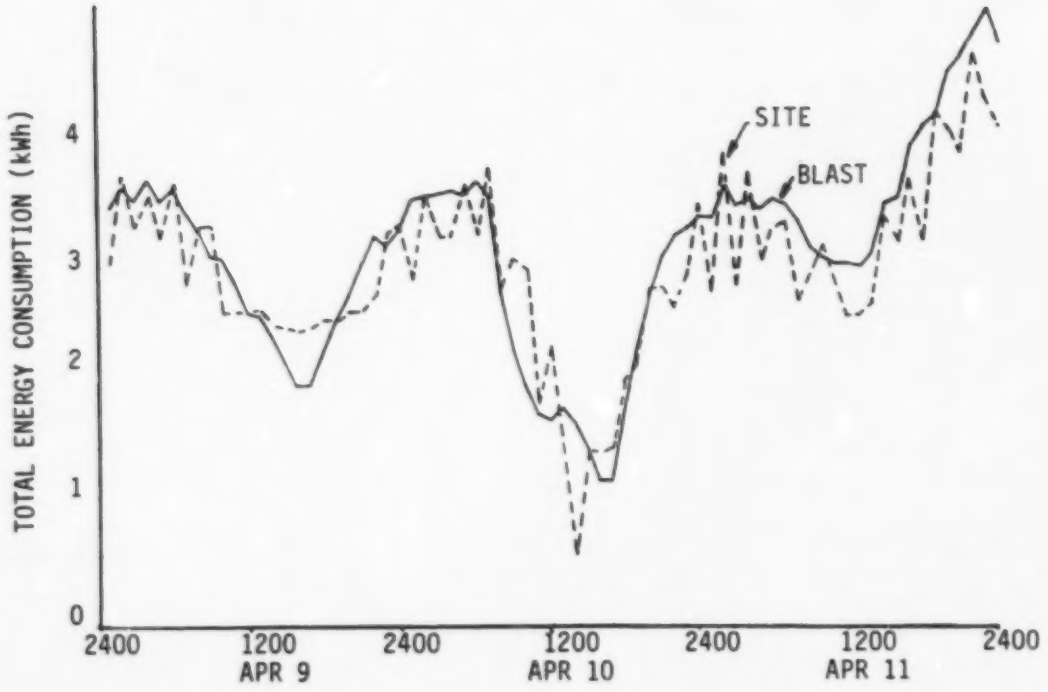


FIGURE 3.6

COMPARISON OF HOURLY TOTAL ENERGY CONSUMPTION
SITE MEASUREMENTS VS BLAST
STANDARD HOUSE (#5)

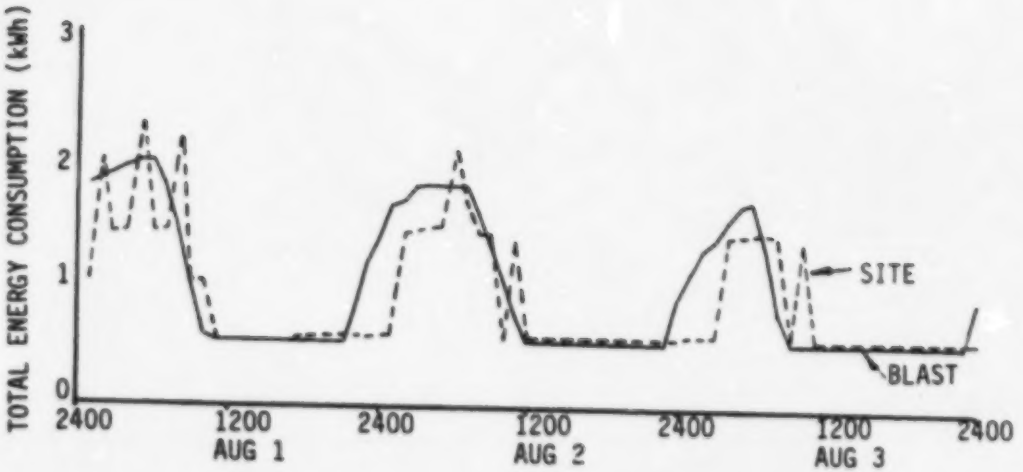


FIGURE 3.7

COMPARISON OF HOURLY TOTAL ENERGY CONSUMPTION
SITE MEASUREMENTS VS BLAST
STANDARD HOUSE (#5)

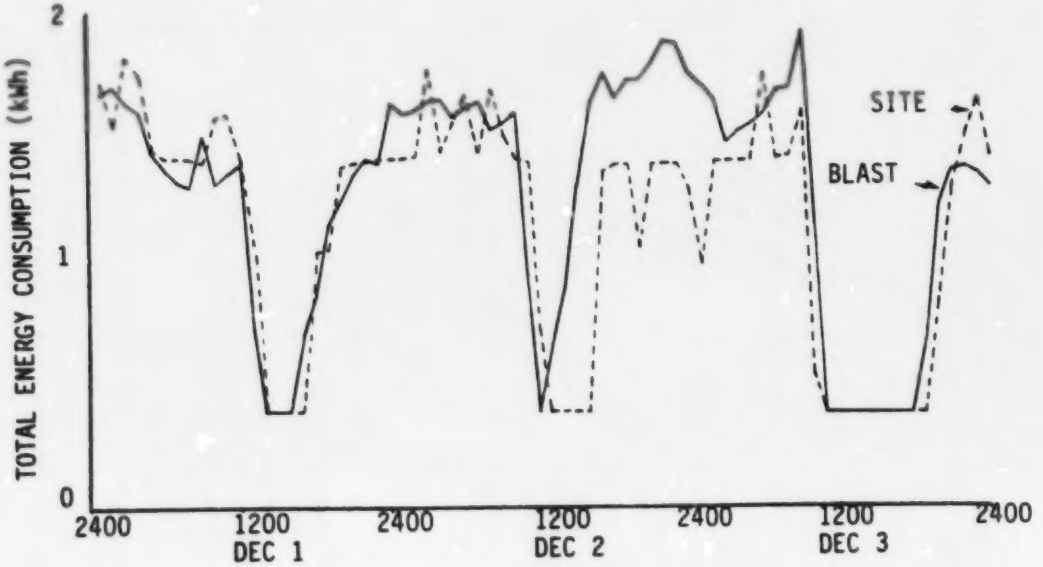


FIGURE 3.8

COMPARISON OF HOURLY TOTAL ENERGY CONSUMPTION
SITE MEASUREMENTS VS BLAST
ENERGY EFFICIENT HOUSE (#3)

TABLE 3.9

COMPARISON OF PEAK ENERGY DEMAND
SITE MEASUREMENTS VS BLAST
(kW)

	STANDARD HOUSE (#5)		ENERGY EFFICIENT HOUSE (#3)	
	SITE	BLAST	SITE	BLAST
Peak Demand	6.28	6.98	3.15	2.76
Date	81-12-31	81-12-30	81-02-11	81-01-07
Time	900h	700h	900h	1000h

3.3.3 Daily Comparison

A comparison of the total metered energy consumption and the BLAST prediction for selected periods is given in Table 3.10. As previously discussed, these periods were selected at various times of the year, depending on the continuity of the metered data. Referring back to Tables 3.6 and 3.7, it appears that the differences may be attributed to the deviation in climatic conditions. On the days when BLAST predicts a higher total energy consumption than the site measurements, the windspeed used by BLAST is much larger than recorded. This will affect the infiltration rate, and result in a larger total energy consumption. The ambient temperature will also affect the infiltration heat loss. If the ambient temperature is lower, the infiltration heat loss will be greater and the total energy consumption will increase. The total horizontal radiation contributes to the freeheat gains. If there is less radiation, the freeheat gains will be lower and the total energy consumption will increase. The effect of these factors has a different magnitude for the two houses and thus effects cannot be generalized. It is, therefore, difficult to determine an exact cause for the differences because only the total energy consumption was monitored on site, and because the factors counterbalance themselves.

3.3.4. Annual Comparison

The monthly energy consumptions of the two houses as predicted by BLAST are compared to the site measurements in Figure 3.9. This figure indicates a good correlation between site measurements and the BLAST predictions. Table 3.11 lists the monthly energy consumption recorded on site, the BLAST prediction and the percent error. On an annual basis, the error in the standard house is 1% and the error in the energy efficient house is 7.6%. The percent error actually ranges more widely on a monthly basis. Deviations could be caused by the following:

a) The weather data used by BLAST was recorded in a location several miles away from the test site. Consequently, hourly values of beam and diffuse radiation and windspeed deviated somewhat

TABLE 3.10

COMPARISON OF DAILY TOTAL ENERGY CONSUMPTION
SITE MEASUREMENTS VS. BLAST

		STANDARD HOUSE (#5)			ENERGY EFFICIENT HOUSE (#3)		
		SITE	BLAST	% ERROR	SITE	BLAST	% ERROR
JAN	1	101.6	100.1	-1.5%	33.5	34.4	2.7%
	2	107.9	103.5	-4.1%	36.2	35.5	-1.9%
	3	96.2	95.0	-1.2%	32.4	31.8	-1.9%
APR	9	66.9	68.9	3.0%	34.0	36.5	7.4%
	10	60.5	61.5	1.7%	27.4	28.6	4.4%
	11	79.7	87.9	10.3%	39.3	47.4	20.6%
SEP	5	29.6	29.3	-1.0%	14.5	16.4	13.1%
	6	28.6	29.2	2.1%	12.0	15.5	29.2%
	7	26.3	24.0	-8.7%	10.7	13.0	21.5%
DEC	1	74.2	73.3	-1.2%	30.2	29.1	-3.6%
	2	75.6	80.8	6.9%	29.6	36.0	21.6%
	3	77.5	78.0	0.6%	23.8	26.5	11.3%

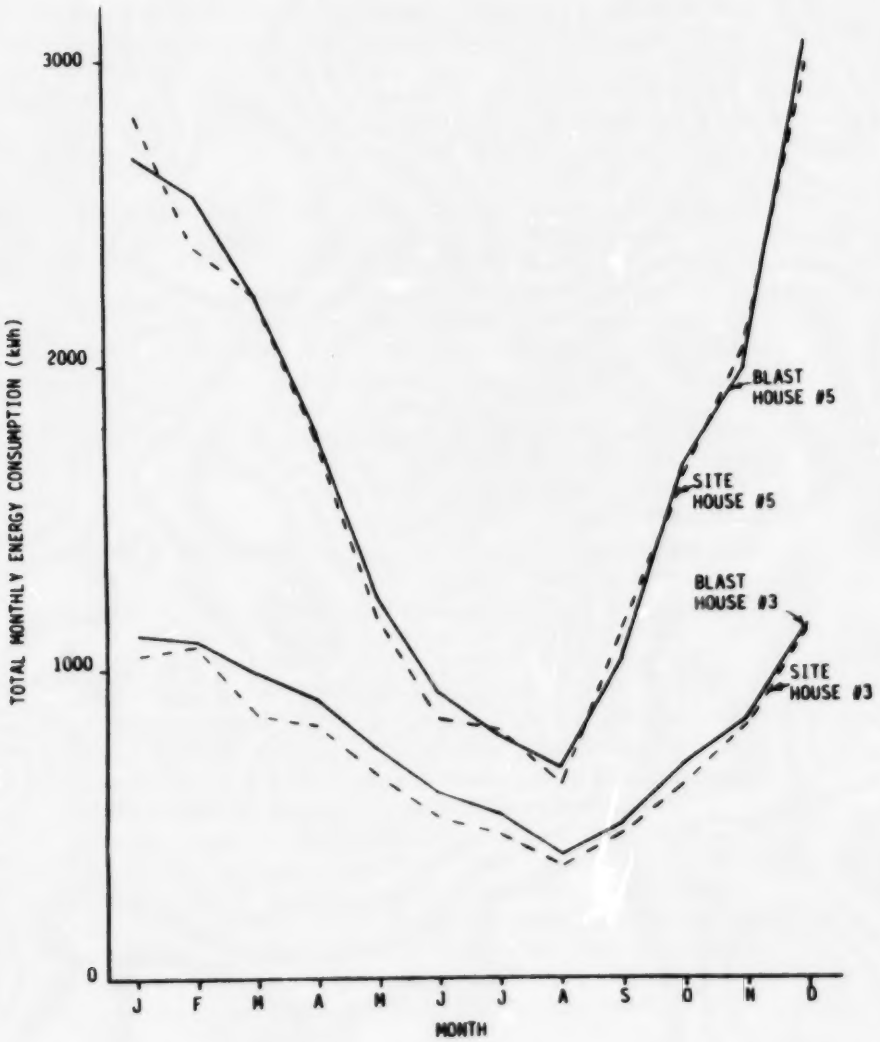


FIGURE 3.9

COMPARISON OF TOTAL MONTHLY ENERGY CONSUMPTION
SITE MEASUREMENTS VS BLAST
STANDARD HOUSE (#5) AND ENERGY EFFICIENT HOUSE (#3)

TABLE 3.11

COMPARISON OF TOTAL ENERGY CONSUMPTION
SITE MEASUREMENTS VS. BLAST

	STANDARD HOUSE (#5)			ENERGY EFFICIENT HOUSE (#3)		
	SITE	BLAST	% ERROR	SITE	BLAST	% ERROR
JAN	2823.5	2690.7	-4.7%	1047.2	1110.0	6.0%
FEB	2393.9	2565.9	7.2%	1070.8	1098.4	2.6%
MAR	2222.9	2217.7	-0.2%	867.8	993.9	14.5%
APR	1766.0	1787.8	1.2%	822.1	903.6	9.9%
MAY	1174.3	1232.4	4.9%	654.1	741.7	13.4%
JUN	838.9	923.1	10.0%	520.3	598.3	15.0%
JUL	803.9	793.3	-1.3%	475.5	533.0	12.1%
AUG	617.0	686.3	11.2%	377.8	401.5	6.3%
SEP	1128.0	1030.0	-8.7%	476.4	500.5	5.1%
OCT	1629.9	1680.7	3.1%	621.1	696.4	12.1%
NOV	2058.1	1990.8	-3.3%	813.4	829.2	1.9%
DEC	2981.2	3046.7	2.2%	1130.2	1145.2	1.3%
ANN	20437.6	20645.4	1.0%	8876.7	9551.7	7.6%

from site measurements. This would have a more significant effect in the energy efficient house where solar gains and infiltration heat loss are major factors in the total energy consumption. If the windspeed used by BLAST is higher than site measurements, the infiltration rate will be higher, and thus the total energy consumption would also be higher. If the solar radiation used by BLAST is lower than site measurements, the solar gains would be lower and thus the total energy consumption would be higher.

b) The effective thermal resistance values of building components used by BLAST may not be exactly the same as the actual values. (It should be noted that only the thermal resistance of the main exterior walls was measured. A heat flux plate was placed on the north wall, steady-state was assumed and the long term average was used to calculate RSI. In the standard house BLAST used RSI 2.00 and the measurement was RSI 1.85. In the energy efficient house BLAST used RSI 6.75 and the measurement was RSI 7.42). It was also difficult to simulate the shutter operation in the energy efficient module. The shutter thermal resistance was measured to be RSI 1, which is much lower than the expected value of RSI 1.76 for 5 cm of polystyrene. It was observed that eight to ten hours were required to reach steady-state, and until that time the shutter had almost no insulation value. BLAST assumed that the shutter operated perfectly for the entire simulation period, when in fact it had been stuck (in both the open and closed positions) at various times of the year. If the shutter was stuck closed, there would be no solar gains through the large south window for that period, and the energy consumption would thus be increased.

c) The correlation for infiltration was based on 500 measurements taken over a period of three months from December 1981 to Febuary 1982, and the correlation to determine the coefficients used by BLAST correlation was developed, by University of Alberta staff, using only the December readings. It was assumed that

this could be extrapolated for the entire 1981 year. It is quite probable that this is a major contributing factor to the difference between metered data and the BLAST prediction of energy consumption, particularly in the energy efficient module. Both houses have a very good correlation for energy consumption for the month of December.

d) The ground temperatures used in the BLAST simulation were monthly averages estimated from recorded ground temperatures. This is important for two reasons. The first is that BLAST performs an hour-by-hour simulation, and thus, using monthly averages will affect the overall temperature difference between the ground and the interior space. The second reason is that the ground temperature profile was based on data recorded 100 km away from the site at an undisturbed location 3 m below the surface.

By removing some of these remaining discrepancies in the input data the BLAST simulation could have been refined to achieve a more precise prediction of annual energy consumption. However, it was not within the scope of this project, considering the time and money required to collect more accurate information on infiltration and ground temperature, to make these adjustments. The comparisons produced were good enough to verify the BLAST model. Because of the use for which BLAST was being verified (the further verification of simpler programs), it was not necessary to verify the input data more precisely.

4.1 Discussion of Results

Analysis of the BLAST predictions and site measurements of annual energy consumption of the two houses indicated some limitations to the study. Infiltration and ground temperature measurements were available, but the times and locations were not exactly as desired. Site measurements of weather parameters were incomplete and the AES weather data deviated from the data obtained at the site. Obviously, these difficulties could be avoided in a verification project which included an experimental study. In the present case that was not possible due to time and budget limitations. It was necessary to use experimental data which was obtained for other purposes by other researchers.

In spite of these and other minor discrepancies in the input data, the overall agreement between the BLAST predictions of energy consumption and temperature and the measured data are close enough when compared on an hourly, daily, monthly and annual basis to indicate that the program is functioning correctly in all the areas utilized in the present analysis, and that the algorithms model correctly the major energy flows.

The test houses used contained only one internal energy source, a fan which operated continuously. Therefore there was no verification that BLAST deals correctly with more complex internal gains from sources which operate intermittently or which emit substantial amounts of radiation. However, the manual calculations reported in Chapter 3 verify that there is no significant problem in BLAST's approach to internal heat gains. The details of the radiative transfer between internal heat sources and the building walls and partitions were not checked manually, but this level of sophistication is far beyond that of any of the programs which BLAST will be used to verify.

A considerable amount of the data measured during the one year tests of the houses was unusable due to instrumentation problems. However, in

selected periods for which the measurements were complete, an hour-by-hour comparison was performed. Of course, this comparison assumed that the site measurements (that did not have missing data) were reliable. Accepting this assumption, the hour-by-hour BLAST predictions appear to be accurate, indicating that the transient simulation section of the program works well.

The infiltration coefficients supplied to BLAST were based on only one month (December) of hour-by-hour infiltration measurements. It was obvious from an examination of the coefficients that a correlation based on a wider range of temperatures could have provided a set of coefficients which would produce a more accurate hour-by-hour prediction of infiltration. It was also known, from discussions with Dr. Wilson of the Department of Mechanical Engineering, University of Alberta, who directed the infiltration research, that wind direction was a significant correlating variable. However, it was not included in the correlation he produced, and BLAST does not consider wind direction in its simulation of infiltration. These factors undoubtedly caused some inaccuracy in the prediction of infiltration heat loss. Since infiltration losses contribute about 25% of the total heat load of the test houses, this probably accounts for a substantial fraction of the deviations between the BLAST predictions and the measured hour-by-hour heat loads and temperatures.

Keeping in mind the discrepancies produced by these minor errors in the input data, the agreement between the BLAST predictions and the monitored temperatures and power consumptions is good enough to indicate that there were no significant mistakes in the building models described by the input data or in the segments of the BLAST program used in the analysis of these models. The data were compared on an hourly basis, on a daily basis, and on a monthly basis, as well as on the basis of the annual total power

consumption. No deviations were found which appeared to be the result of systematic errors; what small deviations which did occur were of the magnitude and type which would be expected to occur as a result of the small input errors discussed above. It was therefore concluded that BLAST would do a very satisfactory job of analysing the monthly power consumptions of a set of standard house models, for verification of the predictions made by several simplified energy analysis procedures.

POOR

QUALITY

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